Rheological Comparison of Bentonite Based and KCl/Polymer Based Drilling Fluids

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ABSTRACT

API standards specify drilling fluid testing criteria, important for their performance. Fluids with equal density, viscosity and gel strength according to these criteria still perform differently, especially regarding hole cleaning efficiency. To investigate this discrepancy, two water based fluids, a bentonite and a KCl/polymer based fluid, with identical properties according to API-13I, was studied. A detailed rheological exmination showed that the bentonite fluid has a strong gel-like character and good long-term storage capabilities, while the KCl/polymer fluid has shorter regeneration time following shear stress. We here show how a thorough rheological analyzis can add a valuable supplement to API standard tests.

INTRODUCTION

Oil well drilling fluids should fulfill diverse requirements including maintaining formation integrity and controlling formation pressures, as well as transporting cuttings to the surface. In order to meet these demands, drilling fluids have become more complex and expensive. It is vital for the drilling operator to be able to make a qualified choice of fluid appropriate for each individual well to ensure a safe and efficient drilling operation.

API/ISO standards specify a set of tests for characterization of drilling fluids. However, fluids that are tested to have equal properties according to these standards are observed to perform significantly different when used in the field[1-3]. In particular, this applies to hole cleaning effects in which oil based drilling fluids have superior performance compared to water based drilling fluids with apparently equal properties[4]. Tests with clay water based fluid systems and water polymer based systems show differences in hole cleaning behaviour between the fluids although they give the same response to tests in API-13I (2009). This occurs also if tested in controlled laboratory conditions[5]. The reasons for this are so far not fully understood and this gives motivation for the present study.

The overall aim of the full R&D project is hence to provide a thorough comparison of different oil and water based drilling fluids with respect to hole cleaning performance in light of the issues presented above. This includes testing of the fluids in a realistically scaled flow loop as well as performing detailed fluid analysis in the lab. This presentation will give results for the lab fluid analyzes for two water based drilling fluids. The two fluids, a bentonite fluid and a KCl/polymer based fluid, were designed to have equal properties as tested by the API-

13I (2009)/ISO10416 (2008), i.e. equal density, and equal viscosity and gel strength as measured by a Fann viscometer. Further a detailed viscosity measurement along with an examination of viscoelastic properties have been performed using an Anton Paar MCR 102 rheometer.

EXPERIMENTAL

Drilling fluid design

Based on previous work[6], two water based fluids were prepared, one bentonite fluid and one KCl/polymer fluid. The fluid composition was modified to create fluids with comparable density, viscosity and gel strength according to ISO 10414-1. Recipes are given in Table 1. All chemicals were received from MI Swaco. The fluids were mixed following the procedure described for KCl drilling fluids in API-13I, chapter 12.6, except for the mixing speed. Two batches of each fluid were prepared. One batch was prepared in a Waring laboratory blender (LB20es) at high shear at a mixing speed of 11 500 rpm, as stated in the API, whereas the other batch was prepared at low shear mixing in a Kenwood mixer (kMix HM791) at 1 650 rpm. The low shear mixing was done to facilitate comparison at a later stage of the current fluid analyses data with data from the flow loop. In the flow loop mixing tank the fluids are mixed at low shear. Mixing at both high and low shear also enables a study of the effect of mixing energy on fluid properties. Briefly, all chemicals except barite were mixed with water for 5 min, followed by dislodging of any material adhering to the sides of the container, and continued mixing for additionally 10 min, resulting in a total mixing time of 15 min. After addition of barite, the same mixing procedure with 5+10 min at low shear was repeated.

Table 1. Fluid composition in weight percent (%).

KCl fluid	Component	Bentonite fluid
63,31 %	Water	63,81 %
31,79 %	Barite	33,36 %
0,27 %	Xantham gum	0,13 %
	Bentonite	1,83 %
0,14 %	Soda ash	0,87 %
4,49 %	KCl	
100,00 %	Sum	100,00 %

The resulting fluid densities were 1376 kg/m^3 for the bentonite and 1371 kg/m^3 for the KCl fluid.

Fluid characterization

To verify that the fluids were comparable with respect to viscosity and gel strength, the fluids were measured using a Fann35SA viscometer following the procedure described in ISO 10414-1, chapter 6. Dial readings were recorded for 600 rpm and 300 rpm. The 10 s and 10 min gel strength was determined. Results are shown in Table 2.

Density measurements were done on an Anton Paar DMA 4500M densitometer and pH was measured on a Mettler Toledo titrator. All measurements were done at room temperature (21.5°C), and resulting values are displayed in Table 2.

The viscoleastic properties of the two drilling fluids were studied using a Physica MCR102 rheometer from Anton Paar. Storage and loss moduli were measured over the whole strain range at a frequency of 10 s^{-1}. Frequency sweeps were performed at strain within the LVER (Linear Viscoelastic Range) according to the calculated proposal in the MCR software. Time-dependent regeneration after deformation was studied by running a thixotropic 3-interval time test with increasing and decreasing strain amplitude at an angular frequency of 10 rad/s. For the initial strain the LVER proposal from the amplitude sweep was used. The load was increased to 100% and then decreased to the LVER proposal value. After the test, the LVER strain was held for 12.5 min to observe the proportion of regeneration during this time period. The proportion of regeneration was calculated as the ratio between the final measuring point (t_3)/the end of the plateau of the reference (t_1)*100%.

All measurements were performed at 10, 20 and 50°C, but only results for 20°C are shown here. To investigate a wider temperature range, a temperature sweep was run from 0°C-120°C. This analysis was done with shear rate of 50s^{-1} and a temperature increase of 2°C/min.

Concentric cylinder (CC27) was chosen as measuring system, to avoid evaporation of sample at higher temperatures. In addition, a paraffin oil (Mosspar M) film was used as a solvent evaporation stop.

Table 2. pH, density and Fann shear stress measurements for the bentonite and KCl/polymer fluid.

		Bentonite	KCl
pH		10,408	8,950
Density	(g/cm^3)	1,37614	1,37154
Shear	600 rpm[a]	36	34
stress	300 rpm[a]	26	25
(Pa)	10 s gel	8	7
	10 min gel	8	8

[a] 1 rpm = 1,5959 s^{-1}

RESULTS

In the following, unless stated otherwise, only results for the fluid batches mixed at low shear are shown.

Amplitude sweeps

Fig. 1 shows the amplitude sweeps of the bentonite and the KCl/polymer fluids. The bentonite fluid has a larger G'/G" ratio than the KCl/polymer fluid, typical of a stronger gel-like character. The KCl/polymer fluid has a longer LVER and a higher flow point than the bentonite fluid, showing that the former fluid is stable up to higher strain. The latter is more affected by high strain values and shows a faster decomposition of the internal structure at high strain.

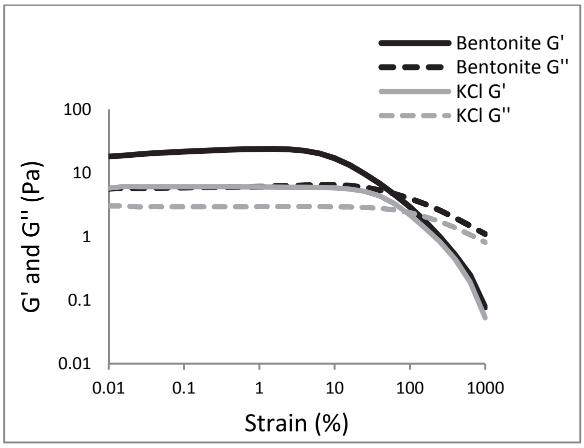

Figure 1. Amplitude sweeps showing storage moduli (G') and loss moduli (G") of the bentonite and KCl/polymer based fluid, performed over the whole strain range at a frequency of 10 s^{-1}.

Frequency sweeps

Time-dependent deformation was studied by running frequency sweeps. For both fluids, the elastic modulus dominates over the viscous modulus, and the cross-over points are high, close to 100 s^{-1}. In the low frequency area, where slow deformation can be studied, the storage and loss moduli of the KCl/polymer fluid are very close. This may indicate that the fluid consists of unlinked molecules[7], and that the long-term stability is low. For 50°C, it was seen that at low frequencies G">G' meaning that the fluid flows very slowly like a highly viscous liquid.

In contrast, the elastic modulus clearly dominates over the viscous modulus for the bentonite fluid. This suggests a gel-like structure of cross-linked clay platelets with long-term stability [7].

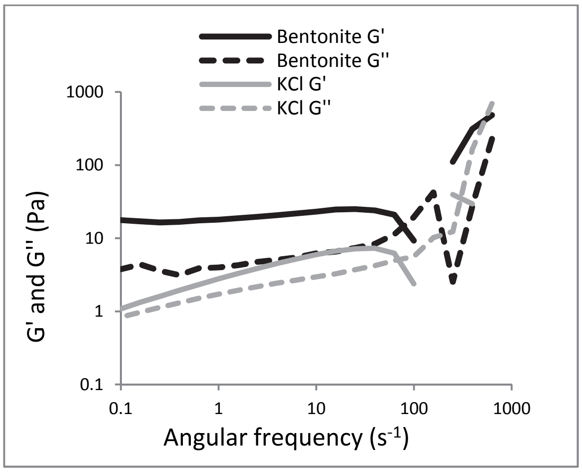

Figure 2. Frequency sweeps showing storage moduli (G') and loss moduli (G'') of the bentonite and KCl/polymer based fluid performed at proposed strain within the LVER.

Flow curves

The flow curves for both fluids, shown in Fig. 3, exhibit shear-thinning behaviour and yield stress at zero strain rate, which are important characteristics of drilling fluids making them efficient for hole cleaning[8]. Yield stress and high viscosity at low shear prevents sedimentation of cuttings, while at high shear the low viscosity helps reducing pumping-power requirements.

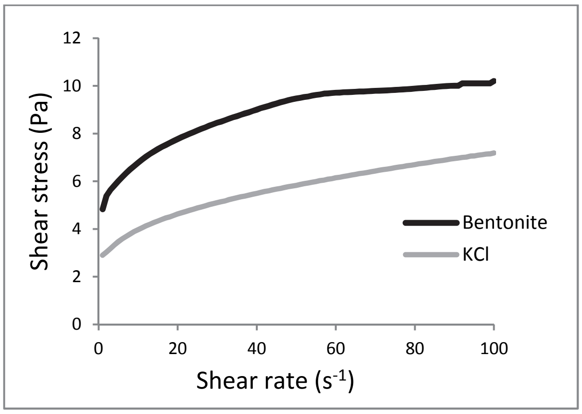

Figure 3. Flow curves of the bentonite and KCl/polymer based fluid.

Effect of temperature

To investigate temperature dependence of the viscosity of the two fluids, temperature sweeps were performed, see Fig. 4. Both fluids show an overall decreasing viscosity with increasing temperature. In addition, bentonite displays a slight increase in viscosity from around 30°C, followed by decreasing viscosity from about 60°C. The reason for this is not understood, but the same phenomenon was seen in various bentonite samples mixed at both high and low shear. However, the phenomenon was much more pronounced for the sample mixed at high shear.

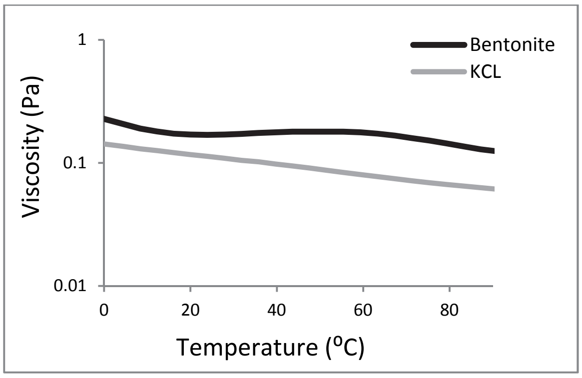

Figure 4. Temperature sweeps of the bentonite and KCl/polymer based fluid at a temperature increase of 2°C/min and shear rate of 50 s^{-1}. Both fluids were mixed at low shear.

Thixotropy

Both of these investigated fluids are thixotropic, i.e. they show time-dependent change in viscosity when subjected to constant shear rate. In drilling operations this provides a low viscosity fluid during fast drilling, while at rest, for example during maintenance, the fluid becomes thick, and thus, can prevent sagging. Both the bentonite fluid and the KCl/polymer fluid are thixotropic and show quick regeneration after high load. However, the bentonite fluid is not fully recovered (79.6%) during the recovery time of this test (12.5 min), while the KCl fluid is close to fully recovered (95.5 %). Both fluids show flow properties (G">G') during high load and gel-like character (G'>G") at LVER strain.

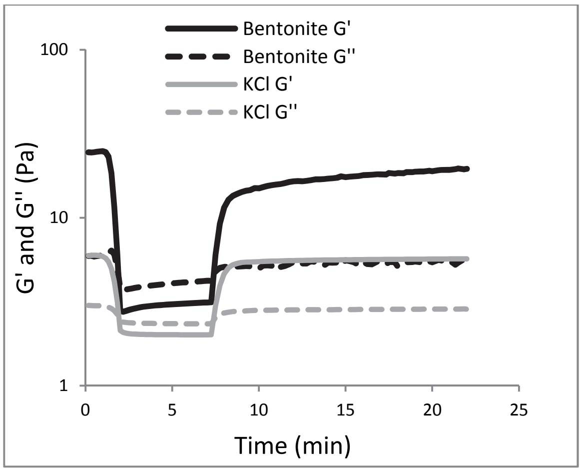

Figure 5. Thixotropic 3-interval time tests for the bentonite and KCl/polymer based fluids.

<u>Effect of mixing energy</u>

To study the effect of mixing energy on the storage and loss moduli of the two fluids, amplitude sweeps were performed on both the high shear and the low shear mixing batches. The results for the bentonite fluid is shown in Fig. 6. For mixing at high shear, the loss modulus develops a peak right before the flow point, indicating that an extra network structure was present at rest and breaks up before the flow point. According to Mezger[7], this may be due to relative motion between molecules or long network bridges which break up before the final breakdown of the internal structure of the fluid. Mixing at high shear also results in a lower flow point, and a shifting of the G' and G" to higher values. The KCl/polymer fluid shows no such influence of mixing energy, i.e. the G' and G" curves (not shown) are close to identical irrespective of mixing energy.

Comparison of flow curves (not shown) for the respective fluids show that for the bentonite fluid, mixing at high shear results in significantly increased viscosity, while for the KCl/polymer fluid the mixing energy has no detectable influence on viscosity.

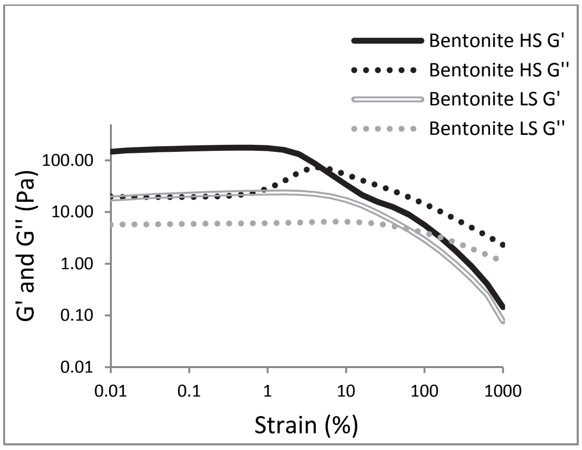

Figure 6. Comparison of amplitude sweeps for the bentonite fluid mixed at high shear (HS, 11 500 rpm) and low shear (LS, 1 650 rpm).

DISCUSSION

It has been observed earlier that the preparation mode of water-clay-polymer systems can have a significant impact on their rheological behaviour and stability over time[9]. Viseras et al.[10] found a linear relation between mixing energy and apparent viscosity in a bentonite-water dispersion system. Mixing may break up clay aggregates and thereby affect the viscosity. This may explain the effect of mixing energy on the viscosity of the bentonite systems. We also note that in the bentonite fluid the viscosity shows a maximum as a function of temperature (see Fig. 4), which is even more pronounced for the bentonite fluid subjected to high shear. As a contrast, no such maximum is seen for the KCl fluids. Quemada[11] developed a model for rheological behaviour based evaluation of structural units, which may be applicable to this system and is suggested as a future investigation.

The two fluids were designed to give comparable viscosities. However, given their different contents, it is not surprising that they exhibit different rheological characteristics. Both fluids contain units capable of giving complex rheology. The KCl fluid contains polymers, whereas the bentonite fluid contains both clays *and* polymers. An additional, potentially important, factor is the concentration of salts. The interplay between solid particles, clays, polymers and salts are likely to cause differences in rheological properties between the two fluids.

CONCLUSIONS

Although the two fluids give almost identical shear stress readings on the Fann viscometer, the above results clearly show that the overall rheological properties of the fluids are far from the same. The storage and loss moduli provide information about gel structure, cross-linking, deformation and regeneration. In this study, we have shown that the bentonite fluid has a stronger gel-like character than the KCl/polymer fluid, which can be explained by the network structure of the thin bentonite platelets. This structure has long-term stability, but takes longer to regenerate after high load. Furthermore, the bentonite fluid is influenced by mixing energy, where high shear mixing yields a more viscous fluid with a stronger network structure.

In a more general context, these results indicate that detailed rheological study of drilling fluids may contribute in explaining observed differences in hydraulic performance and hole cleaning properties for apparently identical fluids.

ACKNOWLEDGMENTS

This work is carried out at the SINTEF fluid laboratory in Bergen. Financial support from the Norwegian research council, Det Norske, Statoil and BG is gratefully acknowledged. The authors thank the industry partners for contributions to technical discussions, and MI Swaco for providing chemicals and technical advice.

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